



MARINE ENVIRONMENT PROTECTION
COMMITTEE
59th session
Agenda item 6

MEPC 59/INF.13
9 April 2009
ENGLISH ONLY

**INTERPRETATIONS OF, AND AMENDMENTS TO, MARPOL
AND RELATED INSTRUMENTS**

**Designation of an Emission Control Area
for nitrogen oxides, sulphur oxides and particulate matter**

Submitted by the United States

SUMMARY

<i>Executive summary:</i>	This document is submitted in support of the proposal to designate an Emission Control Area for specific portions of the coastal waters of the United States and Canada. It provides references and other information considered in developing the proposal
<i>Strategic direction:</i>	7.3
<i>High-level action:</i>	7.3.1
<i>Planned output:</i>	7.3.1.1
<i>Action to be taken:</i>	Paragraph 3
<i>Related documents:</i>	MEPC 59/6/5; MARPOL Annex VI, Appendix III and MARPOL Annex VI, regulations 13 and 14

Background

1 In document MEPC 59/6/5, the United States and Canada propose the designation of an Emission Control Area (ECA) for specific portions of United States and Canadian coastal waters, for the control of nitrogen oxides (NO_x), sulphur oxides (SO_x), and particulate matter (PM) emissions. Adoption of the proposed ECA will result in significant reductions in ambient levels of air pollution in the United States and Canada, which will achieve substantial benefits to human health and the environment.

2 Many in-depth technical analyses were conducted in developing the proposal for a United States/Canada ECA. A comprehensive presentation of the analyses performed by the United States Government has been prepared and is available as a separate technical support document. Due to the length of that document, it is not attached herein. Rather, annex 1 to this document presents a brief synopsis of that technical support document, and in paragraph 1.3

For reasons of economy, this document is printed in a limited number. Delegates are kindly asked to bring their copies to meetings and not to request additional copies.



provides a link to the Internet site where the full document may be retrieved electronically. Annex 2 to this document is a bibliography of materials that are referenced in MEPC 59/6/5, annex 1.

Action requested of the Committee

3 The Committee is invited to note the information provided in this document, and consider it during review of the United States/Canada proposal for an Emission Control Area.

ANNEX 1

ANALYSES IN SUPPORT OF THE PROPOSAL TO DESIGNATE AN EMISSION CONTROL AREA FOR NITROGEN OXIDES, SULPHUR OXIDES AND PARTICULATE MATTER

1 Introduction

1.1 In document MEPC 59/6/5, the United States and Canada propose the designation of an Emission Control Area (ECA) for specific portions of United States and Canadian coastal waters, for the control of nitrogen oxides (NO_x), sulphur oxides (SO_x), and particulate matter (PM) emissions. Designation of the proposed ECA is necessary to protect public health and the environment in the United States and Canada by reducing exposure to harmful levels of air pollution resulting from these emissions. The burden on international shipping is small compared to the improvements in air quality, reductions in premature mortality and other benefits resulting from designation of the proposed ECA.

1.2 Document MEPC 59/6/5 provides a complete analysis of how each of the eight Criteria for Designation of an ECA established under MARPOL Annex VI, Appendix III, is fulfilled. In developing the ECA proposal, many in-depth technical analyses were conducted. A comprehensive presentation of the analyses performed by the United States Government is available as a separate Technical Support Document (TSD). Due to the length of the TSD, it is not attached herein; however, a synopsis of the TSD is presented below.

1.3 The full TSD and other supporting materials may be retrieved electronically on the Internet at the following URL: <http://www.epa.gov/otaq/oceanvessels.htm#emissioncontrol>.

2 Synopsis of Technical Support Document

Emission Inventory

2.1 Chapter 2 of the TSD describes how United States emission inventories were developed to describe air emissions from ships operating in waters within the proposed ECA. These inventories provide the foundation upon which all the subsequent analyses were built, and address Criterion 6 of section 3, Appendix III to MARPOL Annex VI. Beyond the level of detail provided in MEPC 59/6/5, chapter 2 of the TSD explains how the inputs were developed and what assumptions were made in assessing what the emissions are from ships currently (2002 base year), what the emissions would look like in 2020 without the proposed ECA, and what reductions can be expected from the proposed ECA.

2.2 Chapter 2 describes the “bottom-up” methodology that was used, based on the latest state of the art models and inputs. This chapter describes which port-related emissions were included and why, and how emissions were obtained for ships while underway in United States waters. This chapter explains in great detail each parameter that went into the modelling and analyses, including which ships are included, which fuels are used by those ships, which other (non-ECA) emission controls are in place for each scenario, and what growth rates are expected, incorporating forecasts of the demand for marine transportation services in 2020.

Impacts of Emissions on Air Quality, Human Health and the Environment

2.3 Chapter 3 of the TSD describes in great detail most of the analyses conducted in support of Criteria 2, 3, 4 and 5 of section 3, Appendix III, to MARPOL Annex VI. For organizational reasons, the analyses conducted to assess the impacts of ships' emissions on human health are presented in chapter 4 of the TSD, summarized below. Chapter 3 contains several subsections, outlined here for ease of reference.

Impacts of Pollutants on Human Health

2.4 Section 3.1 describes the human health impacts of the pollutants proposed for control in the United States/Canada ECA. The proposed ECA would not only reduce direct emissions of NO_x, SO_x and PM, but also secondarily formed ambient PM and ground-level ozone. Section 3.1.1 describes the nature of these pollutants, formation processes, and relationship to ship emissions. Section 3.1.2 presents the health effects associated with exposure to NO_x, SO_x, PM and ground-level ozone, summarizing the key scientific literature.

Impacts of Ships' Emissions on Air Quality and Benefits of ECA to Air Quality

2.5 Section 3.2 describes the effects of NO_x, SO_x and PM emissions on ambient air quality under the same scenarios for which emission inventories were developed, presented in terms of ground-level ozone and PM. This section also describes the multi-pollutant modelling platform that was used to assess the impacts of reduced marine emissions from the application of the proposed ECA. Appendix A to chapter 3 describes the relevant meteorological conditions that contribute to at-sea emissions being transported to populated areas and contributing to harmful human health and ecological impacts, and which formed inputs to the modelling platform.

Impacts of Ships' Emissions on Ecosystems and Benefits of ECA to Ecosystems

2.6 Section 3.3 describes the impacts of emissions from ships on terrestrial and aquatic ecosystems such as visibility, ozone uptake, eutrophication, acidification, loss of forest biomass, and overall forest health. Using the same scenarios as for the other analyses, improvements in environmental conditions for many types of ecosystems were evaluated. Unlike the analyses for human health, there are a larger number of pollutants of concern to ecosystems. Thus, deposition of many chemical forms of NO_x, SO_x and PM are discussed in this section, as well as the biogeochemical cycles of interrelated pollutants such as mercury.

Impacts of Ships' Emissions on Human Health and Benefits of ECA to Human Health

2.7 Chapter 4 of the TSD presents quantified United States-related health impacts for PM and ozone associated with emissions from ships, both in terms of the expected contribution of overall ship emissions to adverse health impacts on land and the reductions in adverse health impacts that can be expected to occur from the adoption of the proposed ECA.

2.8 The health impacts modelling presented in chapter 4 is based on peer-reviewed studies of air quality and health and welfare effects associated with improvements in air quality. This chapter also describes the computer program used to estimate health benefits by integrating a number of modelling elements (e.g., interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modelled air concentration estimates into health effect incidence estimates.

Cost Analyses

2.9 Chapter 5 of the TSD describes our estimates of the costs associated with the reduction of SO_x, NO_x and PM emissions from ships, not only to the shipping industry but also to marine fuel suppliers and companies who rely on the shipping industry. This chapter provides additional detail regarding the analyses conducted in support of Criteria 7 and 8 of section 3, Appendix III, to MARPOL Annex VI. This chapter describes the analyses used to evaluate the cost impact of Tier III NO_x requirements combined with low sulphur fuel use on vessels operating within the proposed ECA, including estimates of low sulphur fuel production costs, vessel hardware costs, and operating costs. This chapter also presents cost per ton estimates for ECA-based NO_x and fuel sulphur standards and compares these with the costs of established land-based control programmes.

Economic Impact Analysis

2.10 Chapter 6 of the TSD examines the economic impacts of the projected ECA costs on shipping engaged in international trade. This chapter provides additional detail in support of Criterion 8 of section 3, Appendix III, to MARPOL Annex VI. This chapter describes the econometric methodology that was used in estimating two aspects of the economic impacts: social costs and how they are shared across stakeholders, and market impacts for the new engine and new vessel markets.

ANNEX 2

BIBLIOGRAPHY OF MATERIALS FOR MEPC 59/6/5, ANNEX 1 (INFORMATION RESPONDING TO THE CRITERIA IN APPENDIX III TO ANNEX VI)

Section 2 (Description of Area Proposed for ECA Designation)

ICF International. December, 2008. Estimation of diesel particulate matter population exposure near selected harbor areas with revised harbor emissions (revised). Memorandum to U.S. EPA under Work Assignment Number 2-9, Contract Number EP-C-06-094.

Woods & Poole Economics Inc., 2008. Population by Single Year of Age CD. CD-ROM. Woods & Poole Economics, Inc. Washington, D.C.

Section 3 (Contribution of Ships to Air Pollution and Other Environmental Problems)

Byun, D.W., and Schere, K.L., 2006. Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System, *J. Applied Mechanics Reviews*, 59 (2), 51-77.

Gong, W., A.P. Dastoor, V.S. Bouchet, S. Gong, P.A. Makar, M.D. Moran, B. Pabla, S. Ménard, L.-P. Crevier, S. Cousineau, and S. Venkatesh, 2006: Cloud processing of gases and aerosols in a regional air quality model (AURAMS). *Atmos. Res.*, 82, 248-275).

Moran, M.D., Q. Zheng, M. Samaali, J. Narayan, R. Pavlovic, S. Cousineau, V.S. Bouchet, M. Sassi, P.A. Makar, W. Gong, S. Gong, C. Stroud, and A. Duhamel, 2007: Comprehensive surfacebased performance evaluation of a size- and composition-resolved regional particulate-matter model for a one-year simulation. *Proc. 29th NATO/SPS Intern. Tech. Mtg on Air Pollution Modelling and Its Application*, Aveiro, Portugal, Sept. 24-28, 8 pp.

NARSTO Synthesis Team (2000). *An Assessment of Tropospheric Ozone Pollution: A North American Perspective*.

U.S. EPA Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. Environmental Protection Agency, Washington, D.C., EPA 600/R-05/004aF-cF, 2006. This document is available in Docket EPA-HQ-OAR-2003-0190. This document may be accessed electronically at: http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_cr_cd.html.

Section 4 (Impact of Emissions from Ships on Human Health)

Dockery, D.W., Pope, C.A. III, Xu, X, et al. (1993). An association between air pollution and mortality in six U.S. cities. *N Engl J Med*, 32,1753-1759. Retrieved on March 19, 2009 from <http://content.nejm.org/cgi/content/full/329/24/1753>.

Federal-Provincial Working Group on Air Quality Objectives and Guidelines for the Canada-Wide Standards (CWS) process. (1998). *National Ambient Air Quality Objectives for Particulate Matter – Science Assessment Document (SAD)*. Summary document retrieved on March 17, 2009 from <http://www.hc-sc.gc.ca/ewh-semt/pubs/air/naaqo-onqaa/>. Full document available on request by email air@hc-sc.gc.ca.

Federal-Provincial Working Group on Air Quality Objectives and Guidelines for the Canada-Wide Standards (CWS) process. (1999). *National Ambient Air Quality Objectives for Ground-level Ozone – Science Assessment Document (SAD)*. Summary document retrieved on March 17, 2009 from <http://www.hc-sc.gc.ca/ewh-semt/pubs/air/naaqo-onqaa/>. Full document available on request by email air@hc-sc.gc.ca.

Health Canada. (2004a). *Human Health Effects of Fine Particulate Matter: Update In Support of The Canada-Wide Standards For Particulate Matter And Ozone*. Retrieved on March 17, 2009 from http://www.ccme.ca/assets/pdf/prrvw_pm_fine_rvsd_e.pdf.

Health Canada. (2004b). *Health Canada Human Health Effects of Ozone: Update in Support of the Canada-Wide Standards for Particulate Matter and Ozone*. Retrieved on March 17, 2009 from http://www.ccme.ca/assets/pdf/prrvw_oz_hlth_rvsd_e.pdf

Heinrich, U., Fuhst, R., Rittinghausen, S., et al. (1995) Chronic inhalation exposure of Wistar rats and two different strains of mice to diesel engine exhaust, carbon black, and titanium dioxide. *Inhal. Toxicol*, 7, 553-556.

Ishinishi, N., Kuwabara, N., Takaki, Y., et al. (1988) Long-term inhalation experiments on diesel exhaust. In: *Diesel exhaust and health risks. Results of the HERP studies*. Ibaraki, Japan: Research Committee for HERP Studies. pp. 11-84.

Krewski, D., Burnett, R.T., Goldberg, M.S., et al. (2000). *Reanalysis of the Harvard Six Cities study and the American Cancer Society study of particulate air pollution and mortality. A special report of the Institute's Particle Epidemiology Reanalysis Project*. Cambridge, MA: Health Effects Institute. Retrieved on March 19, 2009 from <http://es.epa.gov/ncer/science/pm/hei/Rean-ExecSumm.pdf>.

Mauderly, J.L., Jones, R.K., Griffith, W.C., et al. (1987). Diesel exhaust is a pulmonary carcinogen in rats exposed chronically by inhalation. *Fundam. Appl. Toxicol*, 9,208-221.

National Research Council (NRC), 2008. *Estimating Mortality Risk Reduction and Economic Benefits from Controlling Ozone Air Pollution*. The National Academies Press: Washington, D.C.

Nikula, K.J., Snipes, M.B., Barr, E.B., et al. (1995). Comparative pulmonary toxicities and carcinogenicities of chronically inhaled diesel exhaust and carbon black in F344 rats. *Fundam. Appl. Toxicol*, 25, 80-94.

Pope, C.A., III, Thun, M.J., Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E., and Heath, C.W., Jr. (1995). Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. *Am. J. Respir. Crit. Care Med.*, 151, 669-674.

Pope, C. A., III, Burnett, R.T., Thun, M. J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D., (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *J. Am. Med. Assoc*, 287, 1132-1141.

U.S. EPA (2002). *Health Assessment Document for Diesel Engine Exhaust*. EPA/600/8-90/057F Office of Research and Development, Washington DC. pp1-1 1-2. Retrieved on March 17, 2009 from <http://cfpub.epa.gov/ncea/cfm/recorddisplay.cfm?deid=29060>.

U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at <http://www.regulations.gov/>.

U.S. EPA. (2005). *Review of the National Ambient Air Quality Standard for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper*. EPA-452/R-05-005a. Retrieved March 19, 2009 from http://www.epa.gov/ttn/naaqs/standards/pm/data/pmstaffpaper_20051221.pdf.

U.S. EPA (2006a). *National Ambient Air Quality Standards for Particulate Matter; Proposed Rule*. 71 FR 2620, January 17, 2006.

U.S. EPA. (2006b). *Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final)*. EPA 600/R-05/004aF-cF. Washington D.C.: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at <http://www.regulations.gov/>.

U.S. EPA (2007). *Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper*. EPA-452/R-07-003. Washington, DC, U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at <http://www.regulations.gov/>.

U.S. EPA (2008). *Final Ozone NAAQS Regulatory Impact Analysis*. EPA-452/R-07-008. Prepared by: Office of Air and Radiation, Office of Air Quality Planning and Standards. Retrieved March 17, 2009 from http://www.epa.gov/ttn/ecas/regdata/RIAs/452_R_08_003.pdf

Section 5 (Impact of Emissions from Ships on Ecosystems)

2005 British Columbia Ocean-Going Vessel Emissions Inventory, The Chamber of Shipping of British Columbia, January 25, 2007.

ADF&G. 2008. Predator Management for the Southern Alaska Peninsula Caribou Herd. Alaska Dept. of Fish and Game, Division of Wildlife Conservation.

Amiro, P.G., R.W. Brook, and R.C. Weeber. 2005. Atlantic salmon. Sec. 6.4.5 in Jeffries, D.S., D.K. McNicol, and R.C. Weeber. Chapter 6 – Effects on Aquatic Chemistry and Biology. In: *2004 Canadian Acid Deposition Science Assessment*. Environment Canada, Ottawa.

Arzavus K.M., Dickhut R.M., Canuel E.A. (2001) Fate of Atmospherically Deposited Polycyclic Aromatic Hydrocarbons (PAHs) in Chesapeake Bay. *Environmental Science & Technology*, 35, 2178-2183.

Bradford, R.G., R.W. Brook, and R.C. Weeber. 2005. Atlantic whitefish. Sec. 7.5.3 in Weeber, R.C., D.S. Jeffries, D.K. McNicol (2005) Chapter 7 – Recovery of Aquatic Ecosystems. In: *2004 Canadian Acid Deposition Science Assessment*. Environment Canada, Ottawa.

Chambers, P.A., M. Guy, E.S. Roberts, M.N. Charlton, R. Kent, C. Gagnon, G. Grove, N. Foster (2001) Nutrients and their impacts on the Canadian environment. Agriculture and Agri-food Canada, Environment Canada, Fisheries and Oceans Canada, Health Canada, and Natural Resources Canada. ISBN 0-662-30081-5.

Chappelka A.H.: Samuelson L.J. (1998). Ambient ozone effects on forest trees of the eastern United States: a review. *New Phytologist* 139, 91-108.

Clair T.A., Dennis I.F., Amiro P., Cosby B.J. (2004) Past and future chemistry changes in acidified Nova Scotian Atlantic salmon (*Salmo salar*) rivers: A dynamic modeling approach. 61: 1965-1975.

Cortufo M.F., De Santo A.V., Alfani A., Bartoli G., De Cristofaro A. (1995) Effects of urban heavy metal pollution on organic matter decomposition in *Quercus ilex* L. Woods. *Environmental Pollution*, 89(1), 81-87.

Dickhut R.M., Canuel E.A., Gustafson K.E., Liu K., Arzayus K.M., Walker S.E., Edgecombe G., Gaylor M.O., MacDonald E.H. (2000). Automotive Sources of Carcinogenic Polycyclic Aromatic Hydrocarbons Associated with Particulate Matter in the Chesapeake Bay Region. *Environmental Science & Technology*, 34(21), 4635-4640.

Dillman, Karen L, L.H. Geiser and G. Brenner. "Air Quality Biomonitoring with Lichens: The Tongass National Forest". 2007. JSFS Tongass National Forest. Unpublished report.

Environment Canada (2005). *2004 Canadian Acid Deposition Science Assessment*, Ottawa. [CD-ROM] Available at http://www.msc-smc.ec.gc.ca/saib/acid/assessment2004/index_e.html.

Gawel, J. E.; Ahner, B. A.; Friedland, A. J.; Morel, F. M. M. (1996) Role for heavy metals in forest decline indicated by phytochelatin measurements. *Nature* (London), 381, 64-65.

Heck, W.W.; Cowling, E.B. (1997). The need for a long-term cumulative secondary ozone standard-an ecological perspective. *Environmental Management*, January, 23-33.

Marine Traffic Analysis of the Labrador Region and Eastern Canada, Prepared for Environment Canada by SENES Consultants Ltd., November 28, 2008.

Niklinska M., Laskowski R., Maryanski M. (1998). Effect of heavy metals and storage time on two types of forest litter: basal respiration rate and exchangeable metals. *Ecotoxicological Environmental Safety*, 41, 8-18. Niklinski *et al.*, 1998 – from PM AQCD.

Poor N., Tremblay R., Kay H., et al. (2002) Atmospheric concentrations and dry deposition rates of polycyclic aromatic hydrocarbons (PAHs) for Tampa Bay, Florida, USA. *Atmospheric Environment*, 38, 6005-6015.

Prasad A M; Iverson LR (2003). Little's range and FIA importance value database for 135 eastern U.S. tree species. Northeastern Research Station, USDA Forest Service, Delaware, Ohio; <http://www.fs.fed.us/ne/delaware/4153/global/littlefia/index.html>.

Simcik M.F., Eisenreich, S.J., Golden K.A., et al. (1996) Atmospheric Loading of Polycyclic Aromatic Hydrocarbons to Lake Michigan as Recorded in the Sediments. *Environmental Science and Technology*, 30, 3039-3046.

Simcik M.F., Eisenreich S.J., Liroy P.J. (1999) Source apportionment and source/sink relationship of PAHs in the coastal atmosphere of Chicago and Lake Michigan. *Atmospheric Environment*, 33, 5071-5079.

U.S. EPA (2004). Air quality criteria document for particulate matter. Volumes I and II (Report no. EPA/600/P-99/002aF; 2 Volumes). Research Triangle Park, NC; National Center for Environmental Assessment-RTP; Office of Research and Development; U.S. Environmental Protection Agency.

U.S. EPA (2006). Air Quality Criteria Document for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006.

U.S. EPA (2008). Nitrogen Dioxide/Sulfur Dioxide Secondary NAAQS Review: Integrated Science Assessment (ISA).(Final). U.S. EPA, Washington D.C., EPA/600/R-08/082F.

U.S. EPA (2008). *U.S. EPA's 2008 Report on the Environment* (Final Report). U.S. Environmental Protection Agency, Washington, D.C., EPA/600/R-07/045F (NTIS PB2008-112484).

U.S. EPA (2008, August). Risk and Exposure Assessment for the Review of the Secondary National Ambient Air Quality Standards for Oxides of Nitrogen and Oxides of Sulfur (Draft). First Draft Chapter 1-6. U.S. Environmental Protection Agency, EPA-452?P-08-005a.

Wang, Chengfeng, Corbett, James J. and Firestone, Jeremy. Modeling Energy Use and Emissions from North American Shipping: Application of the Ship Traffic, Energy, and Environment Model. *Environ. Sci. Technol.*, **41**(9), 3226-3232, 2007.

Section 6 (Role of Meteorological Conditions in Influencing Air Pollution)

Alaska Climate Research Center, 2009, Alaska Climatology, <http://climate.gi.alaska.edu/Climate/index.html>.

Clarke, A. D., W. G. Collins, P. J. Rasch, V. N. Kapustin, K. Moore, S. Howell, and H. E. Fuelberg (2001), Dust and pollution transport on global scales: Aerosol measurements and model predictions, *J. Geophys. Res.*, 106(D23), 32,555–32,569.

J. Cote, S. Gravel, A. Maidhood, A. Pateena, M. Roch and A. Stainforth, The operational CMC-MRB Global Environmental Multiscale (GEM) model: part I – design considerations and formulation, *Monthly Weather Review* 126 (1998), pp. 1373-1395.

Draxler, Roland R., and G. D. Hess, 1997, Description of the HYSPLIT-4 modeling system. NOAA technical memorandum ERL ARL, 224. Silver Spring, Md: National Oceanic and Atmospheric Administration.

Grell, G., J. Dudhia, and D. Stauffer, 1994: A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5), NCAR/TN-398+STR., 138 pp, National Center for Atmospheric Research, Boulder CO.

Karamchandani, P., C. Seigneur, and S-Y Chen (2006), Modeling sulfur oxides (SO_x) emission transport from ships at sea, Prepared for U.S. Environmental Protection Agency, Office of Transportation and Air Quality, prepared by Atmospheric & Environmental Research, Inc., San Ramon, CA 94583.

Mesinger, F., G. DiMego, E. Kalnay, K. Mitchell, P. C. Shafran, W. Ebisuzaki, D. Jovi, J. Woollen, E. Rogers, E. H. Berbery, M. B. Ek, Y. Fan, R. Grumbine, W. Higgins, H. Li, Y. Lin, G. Manikin, D. Parrish and W. Shi, 2006: North American Regional Reanalysis. *Bull. Amer. Met. Soc.* 87, 343-360.

Pagé, P. and D'Amours, R., 1994, The operational CMC trajectory model, unpublished.

Wallace, J. M., and Hobbs, P. V. (2006), *Atmospheric science: an introductory survey*. Oxford, Academic.

Western Regional Climate Center, 2009, Alaska prevailing wind directions, <http://www.wrcc.dri.edu/htmlfiles/westwinddir.html>.

Winant C. D., C. E. Dorman, C. A. Friehe, and R. C. Beardsley, 1988: The marine layer off Northern California: An example of supercritical channel flow, *J. Atmos. Sci.*, 45, 3588-3605.

Section 7 (Shipping Traffic in the Proposed Area)

The Chamber of Shipping of British Columbia (2007). 2005 BC Ocean-Going Vessel Emissions Inventory.

SENES Consultants (2008). Marine Traffic Analysis of the Labrador Region and Eastern Canada. Prepared for Environment Canada by SENES Consultants Ltd.

U.S. Department of Transportation Maritime Administration (2008). *U.S. Water Transportation Statistical Snapshot*, May 2008, available from www.marad.dot.gov

Wang, Chengfeng, Corbett, James J., and Firestone, Jeremy. (2007). Modeling Energy Use and Emissions from North American Shipping: Application of the Ship Traffic, Energy, and Environment Model. *Environ. Sci. Technol.*, 41(9), 3226-3232.

Section 8 (Control of Land-based Sources)

Environment Canada (2009), Air Pollutant Emission Summaries and Trends, accessible via <http://www.ec.gc.ca/inrp-npri/>.

U.S. EPA. (2008), *National Emissions Inventory Air Pollutant Emissions Trends Data: 1970 – 2007 Average Annual Emissions*, August 2008, accessible via <http://www.epa.gov/ttn/chief/trends/index.html>.

Section 9 (Relative Costs of Reducing Emissions from Ships)

EnSys Energy & Systems, Inc. and RTI International 2009. Global Trade and Fuels Assessment – Additional ECA Modeling Scenarios. Prepared for the U.S. Environmental Protection Agency.

ICF International. 2007. *Commercial Marine Port Inventory Development, 2002 and 2005 Draft Inventories*, prepared for the U.S. Environmental Protection Agency.

ICF International. 2009. *Costs of Emission Reduction Technologies for Category 3 Marine Engines*, prepared for the U.S. Environmental Protection Agency.

International Maritime Organization, Note by the Secretariat, “Revision of MARPOL Annex VI and NO_x Technical Code; Input from the four subgroups and individual experts to the final report of the Informal Cross Government/Industry Scientific Group of Experts,” Sub-Committee on Bulk Liquids and Gases, 12th Session, Agenda Item 6, BLG 12/INF.10, December 28, 2007.

Research Triangle Institute, “Global Trade and Fuels Assessment – Future Trends and Effects of Designating Requiring Clean Fuels in the Marine Sector”; Research Triangle Park, NC; EPA420-R-08-021; November 2008.

Stopford, Martin, Maritime Economics, 3rd Edition, 2009, Routledge

U.S. EPA. “OAQPS Economic Analysis Resource Document.” Research Triangle Park, NC: EPA 1999. A copy of this document can be found at <http://www.epa.gov/ttn/ecas/econddata/6807-305.pdf>

U.S. EPA “EPA Guidelines for Preparing Economic Analyses.” EPA 240-R-00-003. September 2000, p.113. A copy of this document can be found at <http://yosemite.epa.gov/ee/epa/eed.nsf/webpates/guidelines.html>.
